

## Part D. Section 6: Sodium, Potassium, and Water

### Introduction

Dietary intakes of sodium, potassium, and water have substantial health effects. Excessive sodium intake, especially when accompanied by inadequate potassium intake, raises blood pressure, a well-accepted and extraordinarily common risk factor for stroke, coronary heart disease, and kidney disease (see below for background information on the problem of elevated blood pressure and its control). Adverse effects of sodium on blood pressure appear to begin early in life. Because of worsening blood pressure levels in children in the United States (US), the 2010 Dietary Guidelines Advisory Committee (DGAC) decided to evaluate available research on the health effects of sodium in children, as well as update the 2005 DGAC's review of research on the health effects of sodium in adults. Inadequate potassium intake raises blood pressure and increases the blood pressure response to excess sodium intake.

In addition to their effects on blood pressure, excessive sodium and insufficient potassium likely have other health consequences. Excess sodium intake has been linked to an increased incidence of gastric cancer. Inadequate potassium intake may increase the risk of kidney stones and perhaps osteoporosis. Americans consume excessive sodium and insufficient potassium across the lifespan.

Water is the single largest constituent of the human body and is required to maintain adequate hydration. In the US, water intake appears adequate, without evidence of chronic insufficient or excessive intake.

### List of Questions

#### SODIUM

1. What are the effects of sodium intake on blood pressure in children and in adults?

#### POTASSIUM

2. What are the effects of potassium intake on blood pressure in adults?

#### WATER

3. What amount of water is recommended for health?

## Methodology

The 2005 DGAC based its conclusions regarding these questions on evidence extracted from *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate*, an extensive, systematic review of the scientific literature conducted by an expert panel for the Institute of Medicine (IOM) (IOM, 2005). The conclusions expressed in the 2010 DGAC report are based on that evidence plus subsequent evidence, especially regarding diet and blood pressure in children. Thus, while the vast majority of research on the health effects of sodium, potassium, and water on adults was published before 2005 and synthesized in the 2005 report, this 2010 report builds upon those findings and adds relevant new literature from updated searches. Additional information about the search strategies and criteria used to review each question can be found online in the Nutrition Evidence Library at [www.nutritionevidencelibrary.com](http://www.nutritionevidencelibrary.com). The new focus involves considerably more effort in reviewing the emerging and growing evidence on the blood pressure effects of sodium in children. The overall search strategies used to identify relevant literature and update scientific evidence appear in *Part C. Methodology*.

The following conversions may be useful:

- 2,300 mg of sodium is equivalent to 100 mmol of sodium and is the amount of sodium in 5.84 gm of salt (sodium chloride), about 1 teaspoon of table salt; and,
- 1,500 mg of sodium is equivalent to 65 mmol of sodium and is the amount of sodium in 3.8 gm of salt (sodium chloride), about 2/3 teaspoon of table salt.

## Question 1: What is the Effect of Sodium Intake on Blood Pressure in Children and in Adults?

### Conclusion

A strong body of evidence has documented that in adults, as sodium intake decreases, so does blood pressure. A moderate body of evidence has documented that as sodium intake decreases, so does blood pressure in children, birth to 18 years of age.

### Implications

The projected health benefits of a reduced sodium intake are substantial and include fewer strokes, cardiovascular disease events, and deaths, as well as substantially reduced health care costs. In view of these potential benefits and the current very high intake of sodium in the general population, children and adults should lower their sodium intake as much as possible by consuming fewer processed foods that are high in sodium, and by using little or no salt when preparing or eating foods.

The current food supply is replete with excess sodium. Many foods contribute to the high intake of sodium. While some foods are extremely high in sodium, the problem of excess sodium reflects frequent consumption of foods that are only moderately high in sodium. The major sources of sodium intake among the US population are yeast breads; chicken and chicken mixed dishes; pizza; pasta and pasta dishes; cold cuts; condiments; Mexican mixed dishes; sausage, franks, bacon, and ribs; regular cheese; grain-based desserts; soups; and beef and beef mixed dishes (NCI, 2010). Collectively, this group of foods contributes about 56 percent of the dietary sodium, or nearly 2000 mg per person per day.

A major new concern is the excessive sodium added to products such as poultry, pork and fish through injections or marination; efforts to quantify the amount of sodium from this type of processing are warranted. Finally, an important determinant of sodium intake is calorie intake. Hence, efforts to reduce calorie intake should also lower sodium intake.

In 2005, the DGAC recommended a daily sodium intake of less than 2,300 mg for the general adult population and stated that hypertensive individuals, Blacks, and middle-aged and older adults would benefit from reducing their sodium intake even further. Because these latter groups together now comprise nearly 70 percent of US adults, the goal should be 1,500 mg per day for the general population. Given the current US marketplace and the resulting excessively high sodium intake, it will be challenging to achieve the lower level. In addition, time is required to adjust taste perception in the general population. Thus, the reduction from 2,300 mg to 1,500 mg per day should occur gradually over time. A recent Institute of Medicine report has provided a roadmap to achieve gradual reductions in sodium intake. Because early stages of blood pressure-related atherosclerotic disease begin during childhood, both children and adults should reduce their sodium intake. Individuals should also increase their consumption of dietary potassium because increased potassium intakes helps to attenuate the effects of sodium on blood pressure.

### **Sodium Recommendations of Scientific and Public Health Agencies and Organizations**

Numerous policymaking national agencies and professional public health organizations have recommended a reduced sodium intake as a means to lower blood pressure in the general adult population. In the United States, the National High Blood Pressure Education Program set a sodium intake goal of 2,300 mg (100 mmol) per day as a means to prevent hypertension in non-hypertensive individuals (Whelton, 2002) and as first line and adjuvant therapy in hypertensive individuals (Chobanian, 2003). In 2009, the American Society of Hypertension adopted prior American Heart Association guidelines that called for an upper limit of intake of 2,300 mg per day (Appel, 2009). In early 2010, the American Heart Association lowered its recommended goal to no more than 1,500 mg/day in adults (Lloyd-Jones, 2010). The current Canadian recommendation is less than 2,300 mg of sodium per day; a new policy is expected in June 2010. In Great Britain, the Scientific Advisory Committee on Nutrition in 2003 conducted an independent review of available

evidence and set an upper limit of 2,400 mg of sodium (6 g of salt) per day. In its report, Diet, Nutrition and the Prevention of Chronic Diseases (WHO, 2003), the World Health Organization set an upper limit of 1,600 mg (70 mmol) of sodium per day as a means to lower blood pressure.

Several US public health agencies and two international organizations have established separate sodium recommendations for children. Generally, these recommendations are consistent with either the IOM DRI Adequate Intake (AI) or Tolerable Upper Intake Level (UL) for sodium, and range by age from 400 mg for ages 1 to 3 years to 2,300 mg for ages 14 years and older.

**Table D6.1. Sodium recommendations of scientific and public health agencies and organizations**

Organizations	Date published	Sodium recommendation
<b>United States</b>		
<b>Adults</b>		
American Heart Association	2010	Sodium: $\leq 1,500$ mg per day for adults; The recommendation for 1,500 mg/d does not apply to individuals who lose large volumes of sodium in sweat, such as competitive athletes and workers exposed to extreme heat stress (e.g., foundry workers and fire fighters), or to those directed otherwise by their healthcare provider (Lloyd-Jones, 2010). Web reference (accessed 23 March 2010): <a href="http://circ.ahajournals.org/cgi/content/full/112/13/2061">http://circ.ahajournals.org/cgi/content/full/112/13/2061</a>
American Society of Hypertension	2009	Lower sodium intake as much as possible, with a goal of no more than 2,300 mg/d in the general population and no more than 1,500 mg/d in Blacks, middle- and older-aged persons, and individuals with hypertension, diabetes, or chronic kidney disease (Appel, 2009). Web reference (accessed 23 March 2010): <a href="http://www.ash-us.org/assets-new/pub/pdf_files/DietaryApproachesLowerBP.pdf">http://www.ash-us.org/assets-new/pub/pdf_files/DietaryApproachesLowerBP.pdf</a>
National High Blood Pressure Education Program	2002; 2003	Reduce dietary sodium intake to no more than 100 mmol per day (2,300 mg sodium or 6 g sodium chloride) as a means to prevent hypertension in non-hypertensive individuals (Whelton et al., 2002) and as first line and adjuvant therapy in hypertensive individuals (Chobanian, 2003). Web reference (accessed 23 March 2010): <a href="http://www.nhlbi.nih.gov/guidelines/hypertension/express.pdf">http://www.nhlbi.nih.gov/guidelines/hypertension/express.pdf</a>
<b>Children</b>		
American Academy of Pediatrics	2006	Adopted American Heart Association Position. Sodium recommendation by age: 1-3 yrs $< 1,500$ mg; 4-8 yrs $< 1,900$ mg; 9-13 yrs $< 2,200$ mg; 14-18 yrs $< 2,300$ mg (AHA/Gidding et al., 2006). Web reference (accessed 9 March 2010): <a href="http://pediatrics.aappublications.org/cgi/content/full/117/2/544">http://pediatrics.aappublications.org/cgi/content/full/117/2/544</a>
American Dietetic Association	2008	The current recommendation for adequate daily sodium intake for children 4-8 yrs is 1,200 mg/day and for older children 1,500 mg/day (ADA, 2008). <a href="http://www.adajournal.org/article/S0002-8223(08)00496-3/abstract">http://www.adajournal.org/article/S0002-8223(08)00496-3/abstract</a>
American Heart Association	2005	Based on Dietary Guidelines for Americans, 2005/ IOM DRI Sodium UL by age: 1-3 yrs $< 1,500$ mg; 4-8 yrs $< 1,900$ mg; 9-13 yrs $< 2,200$ mg; 14-18 yrs $< 2,300$ mg (Gidding et al., 2005). Web reference (accessed 23 March 2010): <a href="http://circ.ahajournals.org/cgi/content/full/112/13/2061">http://circ.ahajournals.org/cgi/content/full/112/13/2061</a>
<b>International</b>		
<b>Adults or Mixed Populations</b>		
Australia and New Zealand	2005	Recommends that Australian adults consume less than 2,300 mg of sodium per day (6 g of salt) (NHMRC, 2005). Web reference (accessed 9 March 2010): <a href="http://www.nhmrc.gov.au/files_nhmrc/file/publications/synopses/n36.pdf">http://www.nhmrc.gov.au/files_nhmrc/file/publications/synopses/n36.pdf</a>
Canada	2006	Current Health Canada statement is based on IOM DRI Report: People 14 yrs and older not exceed 2,300 mg of sodium per day. Adequate Intakes (AIs) for good health range from 1,000 mg/d sodium for people 1-3 yrs to 1,500 mg/d for people 9-50 yrs. Sodium Reduction Working Group policy update expected in June 2010 (Health Canada, 2005). Web reference (accessed 9 March 2010): <a href="http://www.hc-sc.gc.ca/fn-an/nutrition/sodium/index-eng.php">http://www.hc-sc.gc.ca/fn-an/nutrition/sodium/index-eng.php</a>

**Table D6.1 (continued). Sodium recommendations of scientific and public health agencies and organizations**

Organizations	Date published	Sodium recommendation
<b>International</b>		
<b>Adults or Mixed Populations</b>		
European Union	2004	EU Framework for Salt Reduction incorporates WHO/FAO recommendation for reducing dietary salt intake to <5-6 g per day (2,000 -2,300 mg/d); 21 of 30 nations directly adopted recommendation, 5 countries adopted a higher interim goal or range, 4 countries reported no dietary sodium guidance (EU, 2009). Web reference (accessed 9 March 2010): <a href="http://ec.europa.eu/health/archive/ph_determinants/life_style/nutrition/documents/national_salt_en.pdf">http://ec.europa.eu/health/archive/ph_determinants/life_style/nutrition/documents/national_salt_en.pdf</a>
Food and Agriculture Organization (FAO)	2003	Population nutrient intake goals for preventing diet-related chronic diseases, Sodium chloride (sodium) <5 g per day (Sodium <2,000 mg per day) (FAO, 2003). Web reference (accessed 9 March 2010): <a href="http://www.fao.org/docrep/005/AC911E/ac911e07.htm">http://www.fao.org/docrep/005/AC911E/ac911e07.htm</a>
Pan American Health Organization (PAHO)	2009	Member nations (n=46) acknowledged WHO/FAO recommendation to reduce dietary sodium intake to <2,000 mg per day for cardiovascular disease prevention through dietary salt reduction (PAHO, 2009). Web reference (accessed 9 March 2010): <a href="http://new.paho.org/hq/index.php?option=com_content&amp;task=view&amp;id=2015&amp;Itemid=1757">http://new.paho.org/hq/index.php?option=com_content&amp;task=view&amp;id=2015&amp;Itemid=1757</a>
United Kingdom	2003	Food Standards Agency set a target to reduce the adult population's average salt intake to 6g (sodium 2,300 mg) per day by 2010 (UK, 2009). Web reference (accessed 9 March 2010): <a href="http://www.food.gov.uk/healthiereating/salt/salttimeline">http://www.food.gov.uk/healthiereating/salt/salttimeline</a>
World Health Organization	2003	Set an upper limit of 70 mmol (1,600 mg) of sodium per day as a means to lower blood pressure. All individuals should be strongly encouraged to reduce daily salt intake by at least one-third and, if possible, to <5 g or <90 mmol per day (WHO, 2007). Web reference (accessed 9 March 2010): <a href="http://www.who.int/cardiovascular_diseases/guidelines/PocketGL.ENGLISH.AFR-D-E.rev1.pdf">http://www.who.int/cardiovascular_diseases/guidelines/PocketGL.ENGLISH.AFR-D-E.rev1.pdf</a>
<b>Children</b>		
Canada	2006	Adequate Intakes (AIs) of sodium for good health for people aged one year and over, range from 1,000 mg/day for children 1-3 yrs to 1,500 mg/day for people 9 yrs and older (Health Canada, 2006). Web reference (accessed 9 March 2010): <a href="http://www.hc-sc.gc.ca/fn-an/nutrition/sodium/index-eng.php">http://www.hc-sc.gc.ca/fn-an/nutrition/sodium/index-eng.php</a>
United Kingdom	2003	The Food Standards Agency issues advice for parents on amounts of salt infants and children should consume: Children: 0-6 months < 1 g (400 mg sodium); 6-12 months - 1g (400 mg sodium); 1-3 yrs - 2g/day (800 mg sodium); 4-6 yrs - 3 g/day (1,200 mg sodium); 7-10 yrs - 5/g day (2,000 mg sodium); 11-14 yrs - 6 g/day (2,400 mg sodium) (UK, 2009). Web reference (accessed 9 March 2010): <a href="http://www.food.gov.uk/scotland/aboutus_scotland/pressreleases/2003/may/121253">http://www.food.gov.uk/scotland/aboutus_scotland/pressreleases/2003/may/121253</a>

## Review of the Evidence: Sodium Intake and Blood Pressure in Children

### **Background**

In the US and most other countries, blood pressure slowly rises with age. The age-related increase in blood pressure begins early in childhood and increases thereafter. The annual increase during childhood is actually greater than during adult life, increasing 1.9 mmHg per year for boys, and 1.5 mmHg for girls, ages 1 to 17 years, compared with 0.6 mmHg per year for US adults (Appel, 2008; National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents, 2004). These data should be viewed in the context of the high blood

pressure epidemic. More than 90 percent of US adults will develop hypertension in their lifetime (Vasan, 2002). Hence, most children, even those with blood pressure in the usual range during childhood, are still at high risk of hypertension as adults. Because high blood pressure is a well established risk factor for cardiovascular disease, preventing the gradual rise in blood pressure during childhood and adolescence could translate into substantial health benefits for Americans of all ages.

Blood pressure during childhood exhibits a significant tracking phenomenon. That is, children tend to retain their position in the blood pressure distribution over time, relative to their peers. Thus, children who tend to track in the high, borderline high, or high normal percentiles of blood pressure for age, sex, and height, are at greater risk of eventual hypertension than are children who tend to track in the lower ranges of blood pressure. Chen and Wang (2008) conducted a meta-analysis that included 50 pediatric cohort studies of blood pressure tracking, and found strong evidence for blood pressure tracking from childhood to adulthood. They concluded that childhood blood pressure is associated with blood pressure in later life, and therefore, early intervention is important.

Recent evidence shows that mean blood pressure levels have increased among US children and adolescents over the past two decades. Muntner et al. (2004) compared the blood pressure of US children, aged 8 to 17 years, in the National Health and Nutrition Examination Survey (NHANES) III (1988-94; n=3496) with the blood pressure of similar-aged youth in NHANES 1999-2000 (n=2086). In the latter survey, mean systolic blood pressure had increased by 1.4 mmHg, and mean diastolic blood pressure by 3.3 mmHg (after adjustment for age, race, and sex). After further adjustment for body mass index (BMI) distribution at each time period, the increase in systolic blood pressure was reduced by 29 percent and for diastolic blood pressure by 12 percent. Greater increases were seen among some subgroups of minority youth, especially boys. Among non-Hispanic Blacks, mean systolic blood pressure levels increased by 2.9 mmHg among boys and 1.6 mm Hg among girls compared with non-Hispanic Whites. Among Mexican Americans, mean systolic blood pressure levels increased by 2.7 mmHg among boys and 1.0 mm Hg among girls compared with non-Hispanic Whites. During the same time period the prevalence of hypertension<sup>1</sup>

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<sup>1</sup> Hypertension in children and adolescents is defined as systolic or diastolic blood pressure equal to or greater than the 95<sup>th</sup> blood pressure percentile of sex-, age- and height-specific blood pressure percentiles. Pre-hypertension is defined as systolic or diastolic blood pressure equal to or greater than the 90<sup>th</sup> percentile but less than the 95<sup>th</sup> percentile, or a blood pressure of greater than 120/80 but less than the 95<sup>th</sup> percentile of sex-, age- and height-specific blood pressure percentiles (National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescents, 2004).

increased by 2.3 percent and the prevalence of pre-hypertension increased by 1.0 percent among children and adolescents (Din-Dzietham, 2007).

The shift in mean blood pressure levels toward higher values for US youth, and the increased prevalence of hypertension and pre-hypertension, are of public health concern, not only because of increased risk of cardiovascular disease (CVD) morbidity and mortality in adult life, but because studies have now shown that elevated blood pressure in childhood results in significant cardiovascular dysfunction and pathology during childhood itself (Daniels, 1998; Mahoney, 1996; McCarron, 2000; McGill, 2000; Soto, 1989; Tracy, 1995). For example, in a study of 130 hypertensive children and youth, ages 6 to 23 years, 55 percent were found to have left ventricular hypertrophy<sup>2</sup> (left ventricular mass index >90<sup>th</sup> percentile). Additionally, 14 percent had left ventricular mass index greater than the 99<sup>th</sup> percentile, and 8 percent had a left ventricular mass index above 51 g/m<sup>2.7</sup>, a cut-point associated with a fourfold increase in risk of CVD endpoints in adults with hypertension (Daniels, 1998). The authors also report that sodium intake was significantly higher among youth with severe left ventricular hypertrophy compared with those with normal left ventricular mass (Daniels, 1998).

High blood pressure, as well as other CVD risk factors, when present in childhood, have been shown to be strongly associated with the extent of early atherosclerotic fatty streaks and fibrous plaques in the aorta and coronary arteries. The Bogalusa Heart Study group performed autopsies on 204 young people, aged 2 to 39 years, most of whom died from trauma. Investigators had data on childhood ante-mortem risk factor status for 93 of these individuals. Systolic blood pressure, diastolic blood pressure, BMI, and serum lipid and lipoprotein concentrations in childhood were all strongly associated with the extent of fatty streaks and fibrous plaques in the aorta and coronary arteries seen at autopsy (Berenson, 1998). Thus, high blood pressure in youth promotes the development of atherosclerosis, the progression of which is greatly enhanced in the presence of other CVD risk factors, such as obesity, dyslipidemia, and cigarette smoking.

As in adults, several dietary factors likely raise blood pressure in children. In addition to excess sodium intake, other possible factors include excess weight and insufficient potassium intake. Both systolic and diastolic blood pressure are higher on average among overweight children and adolescents, compared to normal weight peers (Sorof, 2004). Based on studies in adults, diets rich in potassium might lower blood pressure and lessen the adverse effects of sodium on blood pressure. As discussed below, the largest volume of research on dietary factors on blood pressure in children has focused on the effects of excess sodium intake.

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<sup>2</sup> Left ventricular hypertrophy is an enlargement of the muscle tissue that makes up the wall of the left ventricle, the heart's main pumping chamber.

***Evidence on the Relationship Between Sodium Intake and Blood Pressure in Children***

A systematic review of the literature identified 19 studies (15 trials and 4 prospective observational studies). Although the vast majority of studies were small (and therefore underpowered) or had another methodological limitation, they showed a consistent pattern of lower blood pressure in those groups with a reduced sodium intake.

Of the 15 trials, 14 were randomized controlled trials (RCTs) (Calabrese and Tuthill, 1985; Cooper, 1984; Gillum, 1981; Hofman, 1983; Howe, 1985; Howe, 1991; Lucas, 1988; Myers, 1989; Palacios, 2004; Pomeranz, 2002; Sinaiko, 1993; Trevisan, 1981; Tuthill and Calabrese, 1985; Whitten and Stewart, 1980). Five of the RCTs were methodologically strong (Gillum, 1981; Hofman, 1983; Howe, 1991; Sinaiko, 1993), seven were methodologically neutral (some potential for bias) (Calabrese and Tuthill, 1985; Cooper, 1984; Howe, 1985; Myers, 1989; Palacios et al. 2004; Pomeranz, 2002; Whitten and Stewart, 1980), and two were methodologically weak (Lucas, 1988; Trevisan, 1981). The 15<sup>th</sup> trial, a methodologically strong study (Ellison, 1989), was the largest and longest trial, a two-period cross-over study conducted in two boarding schools.

Four other studies provided evidence that supported this conclusion. One, a methodologically strong study, was a 15-year follow-up of an infant RCT conducted by Hofman et al. (1983) in the Netherlands (Geleijnse, 1997). Three additional studies were prospective longitudinal cohort studies (Brion, 2008 [neutral quality]; Geleijnse, 1990 [positive quality]; and Smith, 1995 [negative quality]).

Ten of the 14 RCTs achieved contrasts in sodium intake of 40 percent or more between treatment groups or periods (Cooper, 1984; Hofman, 1983; Howe, 1985; Howe, 1991; Lucas, 1988; Myers, 1989; Palacios, 2004; Pomeranz, 2002; Tuthill and Calabrese, 1985; Whitten and Stewart, 1980). Two other RCTs achieved contrasts of 7 to 12 percent (Calabrese and Tuthill, 1985; Trevisan, 1981), and two achieved less than a 2 percent difference between treatment groups (Gillum, 1981; Sinaiko, 1993). Although the extent of sodium reduction often appeared large, the data often came from dietary recalls or dietary histories (in which intakes are often underreported), rather than from 24-hour urine collections, which are considered more accurate reflections of sodium intake.

Twelve of the 15 intervention studies showed a decrease in systolic blood pressure and/or diastolic blood pressure on the low sodium diet (Calabrese and Tuthill, 1985; Cooper, 1984; Ellison, 1989; Hofman, 1983; Howe, 1985; Howe, 1991; Myers, 1989; Palacios, 2004; Pomeranz, 2002; Sinaiko, 1993; Trevisan, 1981; Whitten and Stewart, 1980). Three studies reported no change in blood pressure on a low sodium diet (Gillum, 1981; Lucas, 1988; Tuthill and Calabrese, 1985).

Of the 12 intervention studies that showed a decrease in systolic blood pressure and/or diastolic blood pressure on the low sodium diet, the decrease was statistically significant for all, or a

subset, of the study population in eight of the studies (Calabrese and Tuthill, 1985; Ellison, 1989; Hofman, 1983; Howe, 1985; Myers, 1989; Pomeranz, 2002; Sinaiko, 1993; Trevisan, 1981).

Results from two of the three prospective cohort studies tend to support the results of the intervention trials. The studies by Brion et al. (2008) and Geleijnse et al. (1990) involved prospective cohorts that were followed for 7 years. In the study by Brion et al. (2008), higher sodium intake at age 4 months (but not at 7 months or 7 years) was associated with increased systolic blood pressure at age 7 years. This was consistent with infants younger than age 4 months having greater difficulty excreting a sodium load. In the cohort study by Geleijnse et al. (1990), a higher sodium/potassium ratio was associated with a greater increase in slope of blood pressure change over time. In the methodologically weak infant cohort study by Smith et al. (1995), neither the contrast in sodium intake, nor the actual blood pressure was provided. The authors indicate that in the multivariate analysis, the amount of sodium added to the diet approached clinical significance ( $p=.0751$ ).

The final study included in this evidence review, was a 15 year follow-up study by Geleijnse et al. (1997) of an RCT conducted among infants who participated in the initial trial between birth and age 6 months (Hofman, 1983). In this methodologically strong long-term follow-up study, systolic blood pressure and diastolic blood pressure at follow-up were still lower among children initially assigned to the low sodium diet during infancy, compared with the higher sodium group. The difference for systolic blood pressure was statistically significant ( $p<0.05$ ) and for diastolic blood pressure was of borderline significance ( $p=0.08$ ). These results support the hypothesis that a programming effect of sodium intake in early life on blood pressure may exist, because the difference in blood pressure between treatment groups persisted for 15 years, even though all infants resumed their usual diet when the double-blind trial ended at 6 months of age.

Infancy may be a particularly sensitive period with respect to the effect of dietary sodium on later blood pressure. Young infants, before the age of 4 to 6 months, are less able to respond physiologically to varying concentrations of salt solutions, thus are at greater risk of hypernatremia with higher intakes of dietary sodium. Human milk has a low concentration of sodium, at about 15 mg per 100 ml (Sutton, 2008). In a meta-analysis of 15 studies, breastfeeding during infancy was found to be associated with lower blood pressure at follow-up 3 to 60 years later, compared with bottle feeding (Martin, 2005). Although the differences were small (systolic blood pressure -1.4 / diastolic blood pressure -0.5 mmHg) they were statistically significant. The composition of commercial infant formulas, however, has changed significantly over the past several decades, and although sodium levels of formulas were higher than breast milk before approximately 1980, formulations with sodium levels comparable to human milk were introduced in the US and elsewhere beginning in the mid-1970s (Martin, 2005). Several studies of infants born since 1980, however, still show a blood pressure-lowering effect of breastfeeding compared with formula

feeding, suggesting that breastfeeding may benefit blood pressure through a complex variety of mechanisms in addition to the low sodium content of breast milk. The association of breastfeeding with healthier patterns of infant weight gain, and decreased obesity is likely to be another blood pressure-protective mechanism (Arenz, 2004).

In aggregate, these data document that sodium reduction modestly lowers blood pressure in infants and children. While the degree of reported blood pressure lowering was usually modest, in the range of -1 to -5 mmHg, such an effect, if sustained over time, could translate into reduced blood pressure in adults, and thus reduced prevalence of hypertension. Furthermore, if a reduced sodium intake blunts the age-related rise in blood pressure in children, then the effects of sodium reduction will be greater than projected from these studies. Although, most of the studies had one or more methodological limitations, particularly small sample size (and consequently, inadequate statistical power), brief duration (typically < 1 month), and inadequate or uncertain contrast in sodium intake, these data as a whole point to potential public health benefits of considerable magnitude.

## **Review of the Evidence: Sodium Intake and Blood Pressure in Adults**

### ***Background***

High blood pressure is highly prevalent among American adults. According to the most recent national survey data (1999-2004), nearly a third (32%) of adult Americans have hypertension, and roughly another third are pre-hypertensive (Wang and Wang, 2004; Cutler, 2008). These data also show that the prevalence of hypertension is increasing. Rates of controlled hypertension remain low (< 40%) but are improving slightly (Cutler, 2008).

As stated earlier, in the US, blood pressure generally increases with age throughout the lifespan. As a result, hypertension typically occurs in middle-aged and older adults. Adults 50 years of age and older now have a 90 percent lifetime risk of becoming hypertensive (Vasan, 2002). Some populations are disproportionately affected by hypertension and its adverse health outcomes. For example, pre-hypertensive individuals are at high risk of developing hypertension (Vasan, 2001). Blacks generally have higher blood pressure than do other racial-ethnic groups in the US (Fields, 2004). Blacks also have a higher risk of blood pressure-related complications, particularly stroke (Ayala, 2001; Giles, 1995) and kidney failure (Klag, 1996).

Hypertension is one of the leading causes of death around the world. This is because high blood pressure is a strong, consistent, continuous, independent, and etiologically relevant risk factor for cardiovascular and renal diseases (Chobanian, 2003). Notably, the risk of cardiovascular disease resulting from hypertension has no threshold. It increases progressively from normal blood pressure

through pre-hypertension to hypertension (Lewington, 2002; Vasan, 2001). Nearly a third of blood pressure-related deaths from coronary heart disease occur in people who do not have hypertension (Stamler, 1993).

High blood pressure occurs as a result of environmental and genetic factors and their interactions. Available evidence indicates that dietary factors play a critical role. Although this chapter focuses on the adverse effects of excessive sodium and insufficient potassium intake on blood pressure, other dietary factors, such as overweight/obesity and excess alcohol consumption, raise blood pressure. In individuals without hypertension, dietary changes lower blood pressure and prevent hypertension, which can reduce the risk of related adverse health outcomes. In individuals with stage I hypertension (systolic blood pressure of 140-159 mmHg and/or diastolic blood pressure of 90-99 mmHg), dietary changes can be an initial therapeutic approach before blood pressure medication is prescribed. Among hypertensive individuals who already are on medication, dietary changes can further lower blood pressure and help reduce the number or amount of medications necessary. In general, dietary changes have a greater effect on blood pressure in people with hypertension than in those without. These individual changes could have a huge positive effect on the health of American adults if they translated into even a small reduction in blood pressure across the population.

### ***Evidence on the Relationship Between Sodium Intake and Blood Pressure in Adults***

The 2005 DGAC report previously examined the relationship between sodium intake and blood pressure. As documented in that report, evidence included results of more than 50 clinical trials, as well as meta-analyses that synthesized results (see IOM, 2004, Tables 6-12, 6-13, 6-15, 6-16, and Appendix I). Several of those trials were dose-response studies that examined the relationship of progressively higher levels of sodium intake with blood pressure. A few large trials also tested the effects of sodium reduction as a means to prevent hypertension.

The 2010 DGAC performed an updated literature search to identify new research on the relationship between sodium intake and blood pressure. The Nutrition Evidence Library (NEL) search identified 47 potential articles (15 reviews/meta-analyses and 32 primary studies). A total of 13 articles, 12 primary studies, and one systematic review/meta-analysis, met the eligibility criteria and were reviewed. Of the 12 primary studies, 9 were randomized trials (Cappuccio, 2006; China Salt Substitute Collaborative Group, 2007; Dickinson, 2009; Forrester, 2005; Gates, 2004; He, 2009; Makela, 2008; Pimenta, 2009; Swift, 2005), 2 (He, 2009; Schmidlin, 2007), were studies that tested different levels of sodium intake but in fixed order, and 1 was an observational analysis of a previously published trial (Cook, 2005). Of the 12 primary studies, eight were methodologically

strong and four were methodologically neutral. Enrollment criteria differed substantially by study, with blood pressure criteria that often bridged traditional classification schemes. Still, it appears that five of the studies enrolled normotensive individuals, six enrolled hypertensive individuals, and one explicitly enrolled both normotensive and hypertensive individuals. Trials were conducted in Jamaica, Northern Chinese, US, Australia, Finland, Great Britain, and Nigeria. Populations were demographically heterogeneous (e.g., enrolling Black, White, and Asian hypertensives living in Great Britain).

Because previous trials had already confirmed that sodium reduction lowers blood pressure, the individual trials typically addressed other issues, such as the effects of public health interventions in economically developing countries or the effects of sodium reduction on other variables (e.g., vascular function, arterial compliance, proteinuria, and heart rate variability). Nonetheless, each reported the effects of sodium reduction on blood pressure. In total, a significant reduction in either systolic or diastolic blood pressure occurred in all but one of these studies, and significant reductions in both systolic and diastolic blood pressure in five studies. The eight methodologically strong studies all showed a significant reduction in systolic or diastolic blood pressure, and significant blood pressure reduction in both systolic and diastolic blood pressure occurred in five of the studies. In several studies, relatively few blood pressure measurements were obtained. Hence, in some cases, the absence of significant findings might have resulted from imprecise or inadequate blood pressure measurement.

The methodologically strong systematic review/meta-analysis of 34 randomized controlled trials (He and MacGregor, 2005), which pooled data for 23 trials of hypertensive and 11 trials of normotensive subjects, demonstrated that a modest reduction in sodium intake for 4 or more weeks had a significant effect on blood pressure in both hypertensive and normotensive subjects. It also found a significant dose-response relationship between sodium reduction and both systolic and diastolic blood pressure. In this meta-analysis, a median reduction in urinary sodium of approximately 1.8 g/d (78 mmol/d) lowered systolic/diastolic blood pressure by 2.0/1.0 mmHg in non-hypertensive and by 5.1/2.7 mm Hg in hypertensive adults.

In aggregate, these studies reinforce and further strengthen the previous conclusions from the 2005 DGAC report that sodium reduction lowers blood pressure and benefits extend to both non-hypertensive and hypertensive individuals. As discussed below, the effects of blood pressure reduction are heterogeneous.

### ***Inter-Individual Variability in Blood Pressure Response***

Evidence from a variety of studies, including observational studies and clinical trials, has demonstrated heterogeneity in the blood pressure responses to sodium intake. Such a phenomenon is commonplace because the effects of dietary factors, not just sodium, vary by individual. Those individuals with the greatest reductions in blood pressure in response to decreased sodium intake have been termed “salt sensitive.” Despite the use of the terms “salt sensitive” and “salt resistant” to classify individuals in earlier research studies, the change in blood pressure in response to a change in sodium intake is not binary. Rather, the reduction in blood pressure from a reduced sodium intake has a continuous distribution across individuals. Because no standardized diagnostic criteria and tests exist and blood pressure is highly variable, it is impossible to classify individuals as salt sensitive or not. Nonetheless, some general observations about sodium sensitivity with respect to subgroups of the population can be made.

Individuals with hypertension, diabetes, and chronic kidney disease, as well as middle- and older-aged persons and Blacks tend to be more sensitive to sodium than their healthier, younger, White counterparts. Genetic factors also influence the blood pressure response to sodium. Each of the 14 identified genes that affect blood pressure affects renal sodium handling. Such evidence provides indirect support of an etiologic role of sodium in blood pressure homeostasis (Lifton, 2002).

Sodium sensitivity is modifiable. On average, the rise in blood pressure from increased sodium intake is attenuated in the setting of a high potassium intake (4,700 mg of supplemental potassium per day in one trial [Morris, 1999]; 6,700 mg per day in another trial [Schmidlin et al., 1999]). The rise in blood pressure from increased sodium intake is also attenuated in the setting of the DASH diet, which is rich in potassium (4,600 mg of potassium per day) as well as other minerals (Bray, 2004; Karanja, 1999; Sacks, 2001; Vollmer, 2001). Nonetheless, a dose-response relationship between sodium intake and blood pressure persisted.

## **Relevant Contextual Issues**

### ***Relationship Between Sodium Intake and Cardiovascular Disease***

Evidence of a direct relationship between dietary sodium intake and cardiovascular disease in humans has been sparse, in large part, because of methodological challenges. Direct evidence includes results from clinical trials and prospective observational studies in which outcomes are cardiovascular disease events. To date, three trials conducted in general populations have reported the effects of reduced sodium interventions on such outcomes. Two of these trials tested lifestyle interventions that focused on reducing sodium intake, and one trial tested the effects of a reduced

sodium/high potassium salt. In each instance, a 21 to 41 percent reduction in clinical cardiovascular disease events occurred in those who received a reduced sodium intervention (significant reduction in two trials (Chang, 2006; Cook, 2007) and non-significant trend in the third (Appel, 2001)). Hence, direct evidence from trials, albeit limited, is consistent with evidence on the blood pressure lowering effects of sodium reduction.

In a meta-analysis, Strazzullo et al. (2009) synthesized results from prospective observational studies that evaluated the relationship of sodium intake with stroke and CVD. In their analysis of 13 cohort studies with 19 independent samples, a higher sodium intake was associated with an increased risk of stroke and likely cardiovascular disease. Specifically, a 2,000 mg per day increased intake of sodium was associated with a 23 percent higher risk of stroke (CI = 1.06-1.43;  $p=0.007$ ). The relationship of CVD with sodium intake was not statistically significant (14% greater risk of CVD, CI = 0.99-1.32;  $p=0.07$ ). However, in sensitivity analyses that excluded one study with particularly unreliable estimates of sodium intake, the corresponding effect size was 17 percent and the relationship was statistically significant ( $p=0.02$ ).

The disparate and often poor quality of dietary sodium measurements likely contributed to the significant heterogeneity in study results, observed by Strazzullo et al. (2009). Because of large day-to-day variation in sodium consumption, imprecise and inaccurate measurement techniques, and incomplete assessment of dietary intake, results from prospective observational studies have been inconsistent and occasionally paradoxical. The “gold standard” to assess dietary sodium intake is urinary excretion of sodium as assessed from multiple, complete 24-hour urine collections. Yet only four of the 13 studies collected 24-hour urines, and none of these studies obtained more than one collection. More importantly, several studies had evidence of substantial, non-systematic underreporting of sodium intake, and most other studies provided no data on the completeness of dietary assessment. In view of the methodological limitations of observational epidemiologic evidence, policy makers have relied on the robust body of evidence that links salt intake with blood pressure to guide policy.

### ***Relationship Between Sodium Intake and Gastric Cancer***

Beyond sodium and blood pressure research, observational studies have noted a close relationship of sodium intake and cancer of the stomach. For example, an ecologic analysis of 39 populations in 24 countries documented a direct association between urinary sodium excretion and mortality from stomach cancer (Joossens, 1996). High doses of sodium result in destruction of the mucosal barrier of the stomach such that the mucus membrane is easily invaded by carcinogens (Correa, 1975). The World Cancer Research Fund/American Institute for Cancer Research, recently

reviewed the available evidence and concluded that sodium chloride and foods high in sodium chloride are probable causes of stomach cancer (WCRF/AICR, 2007).

### ***Relationships Between Sodium Intake and Other Health Outcomes***

As documented by the IOM (IOM, 2005), an increased sodium intake might have adverse effects on additional health outcomes. These include subclinical cardiovascular disease (i.e., left ventricular mass), early kidney disease (i.e. proteinuria), and disordered mineral metabolism (e.g., increased urinary calcium excretion, potentially leading to osteoporosis). Cross-sectional studies consistently document an association between urinary sodium excretion and left ventricular mass, but only one small controlled trial assessed the effects of sodium reduction on this endpoint. At least two trials have documented that a reduced sodium intake lowers proteinuria (He, 2009; Swift, 2005). Numerous trials document that a reduced sodium intake lowers urinary calcium excretion (IOM, 2005, Table 6-19), but urinary calcium excretion, by itself, is not a well-accepted surrogate marker for bone mineral density or dietary induced osteoporosis.

### ***Overall Public Health Impact of Reducing Sodium Intake***

Several studies have estimated the potential overall health and cost benefits of a reduced sodium intake (Bibbins-Domingo, 2010; Danaei, 2009; Palar and Sturm, 2009; Smith-Spangler, 2010). A feature of these studies is the use of statistical modeling with a set of linked assumptions, namely that sodium reduction lowers blood pressure, and lower blood pressure reduces the risk of stroke and coronary heart disease. Although evidence of a direct effect of sodium reduction on CVD outcomes is preferred, policy makers consider blood pressure as one of the few surrogate outcomes that is sufficiently robust to guide policy. Additional direct evidence of a link between sodium intake and CVD comes from prospective observational studies and the few available trials with clinical CVD outcomes (see above).

Studies that evaluated the potential benefits and costs of reducing sodium intake have reached the conclusion that the projected benefits are substantial and that sodium reduction is cost-effective. In the most recent and comprehensive of such analyses (Bibbins-Domingo, 2010), a national effort that reduces sodium intake by 1,200 mg/day in the US is projected to have substantial health benefits (Tables D6.2 and D6.3). Even if the intervention reduced sodium intake by just 400 mg/day, the benefits still would be substantial and warrant implementation. Importantly, such a program should generate cost savings.

**Table D6.2. Annual projected benefits, costs, and cost-savings from sodium reduction: higher estimate of benefit**

Benefit	Sodium reduction of 400 mg/day	Sodium reduction of 1,200 mg/day
Heart attacks prevented	32,000	92,000
Strokes prevented	20,000	59,000
Deaths prevented	28,000	81,000
Costs (billions)	\$0.3	\$0.3
Savings (billions)	\$7.0	\$20.4
Dollars saved/Dollars spent	\$26.1 saved per \$1 spent	\$76 saved per \$1 spent

Source: Adapted from Bibbins-Domingo, 2010.

**Table D6.3. Annual projected benefits, costs, and cost-savings from sodium reduction: lower estimate of benefit**

Benefit	Sodium reduction of 400 mg/day	Sodium reduction 1,200 mg/day
Heart attacks prevented	20,000	58,000
Strokes prevented	13,000	37,000
Deaths prevented	17,000	51,000
Costs (billions)	\$0.3	\$0.3
Savings (billions)	\$4.1	\$12.1
Dollars saved/Dollars spent	\$15.4 saved per \$1 spent	\$45.2 saved per \$1 spent

Source: Adapted from Bibbins-Domingo, 2010.

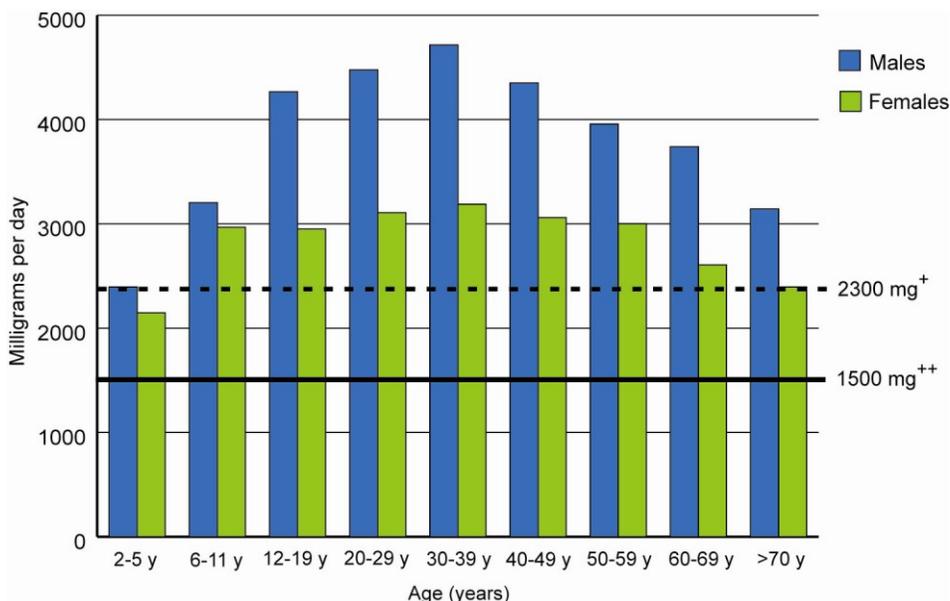
The above estimates do not include the projected long-term benefits from reducing sodium intake in children. As noted above, higher levels of blood pressure in children are strongly associated with early stages of atherosclerosis. Also, blood pressure exhibits a substantial tracking phenomenon—blood pressure levels in children track into adulthood. For these reasons, efforts to lower blood pressure in children through a reduced sodium intake should translate into additional health benefits, beyond those documented above for US adults.

### ***Sodium Intake***

In 2005-2006, the estimated average intake of sodium for all persons in the US ages 2 years and older was 3,436 mg/day (USDA/ARS/FSRG, 2008a). This includes sodium in water, but not salt added at the table or sodium in dietary supplements or medications. Figure D6.1 displays average daily sodium intake by age and sex. The higher sodium intake in men compared to women and the variation by age reflects the high correlation between intakes of sodium and calories. That is, as calorie intake rises, so does sodium intake. At all ages, mean intake exceeded 2,300 mg per day as well as the 1,500 mg per day limit that is recommended for middle- and older-aged adults,

hypertensive individuals and Blacks (currently about 70 percent of the adult population). Mean sodium intake was 3,524 mg/day in non-Hispanic Whites, which was somewhat higher than the mean intake of 3,257 mg/day in non-Hispanic Blacks and 3,162 mg/day in Mexican-Americans (USDA/ARS/FSRG, 2008b).

**Figure D6.1. Estimated mean daily sodium intake, by age/sex group, 2005-2006**



\*Includes water and excludes salt added at the table.

+ 2300 mg is the Upper Limit (UL) for sodium intake in adults set by the IOM. For children younger than 14 years old, the UL is less than 2300 mg/day.

++ 1500 mg is the recommended intake level for middle- and older-aged adults, hypertensive individuals, and Blacks in the 2005 U.S. Dietary Guidelines.

Source: US Department of Agriculture, Agricultural Research Service (USDA, ARS), 2005-2006. What We Eat In America/National Health and Nutrition Examination Survey (WWEIA, NHANES). <http://www.ars.usda.gov/Services/docs.htm?docid=13793>

**Figure D6-1. Data points. All values in milligrams.**

Age (years)	2-5	6-11	12-19	20-29	30-39	40-49	50-59	60-69	>70
Males	2395	3202	4266	4476	4715	4350	3956	3738	3142
Females	2146	2966	2950	3107	3187	3059	3001	2606	2395

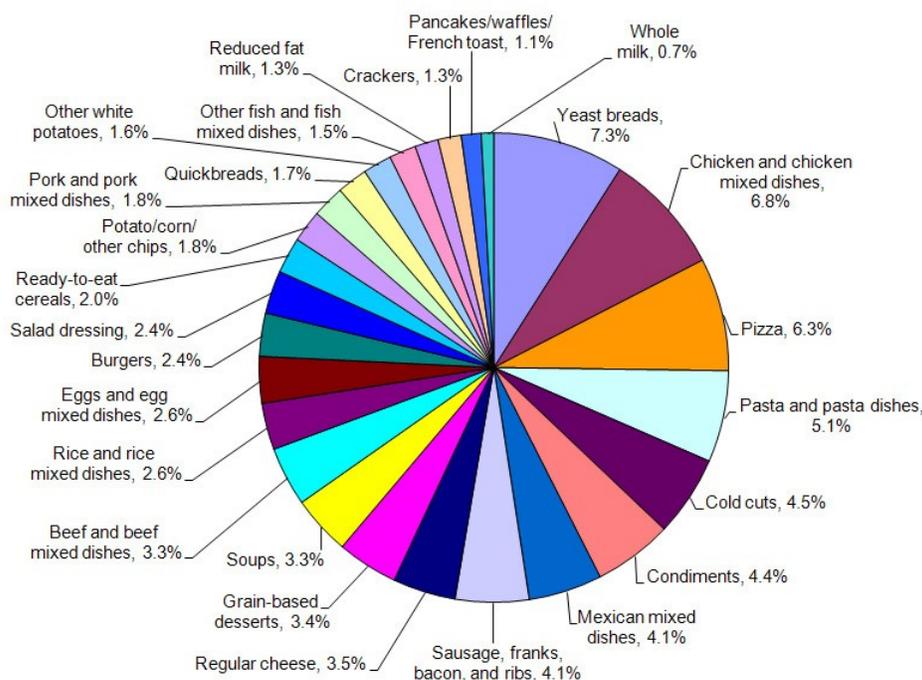
Previous NHANES results have indicated that the average daily sodium intake among persons in the US ages 2 years and older increased from 3,329 mg in 2001-2002, to 3,436 mg in 2005-2006, exceeding in each period even the higher sodium intake limit of 2,300 mg/day recommended in 2005.

### ***Sources of Sodium***

On average, the natural sodium content of food accounts for only 10 percent of total intake, while discretionary salt use (i.e., table and cooking salt) provides another 5 to 10 percent of total intake. The remaining 75 percent is derived from salt added in food processing by manufacturers (Mattes and Donnelly, 1991; Mattes, 1997). Sodium in water softeners and medications typically contributes a very small amount of sodium. When total intake of sodium is decreased, discretionary salt use is fairly stable, even when freely available (Mattes, 1997). Therefore, at the environmental level programs for reducing the sodium consumption of a population should concentrate primarily on reducing the sodium used during food processing (IOM, 2010) and, at the individual level, focus on changes in food selection (e.g., more fresh, less-processed items, lower sodium foods) and preparation (Mattes, 1997).

Many foods contribute to the high intake of sodium. While some foods are extremely high in sodium, the problem of excess sodium reflects frequent consumption of foods that are only moderately high in sodium. As shown below, in 2005-2006, the major sources of sodium intake among the US population were yeast breads; chicken and chicken mixed dishes; pizza; pasta and pasta dishes; cold cuts; condiments; Mexican mixed dishes; sausage, franks, bacon, and ribs; regular cheese; grain-based desserts; soups; and beef and beef mixed dishes. Each of these 12 food groups supply more than 100 mg sodium per person per day to the diet. Collectively, this group of foods contributes about 56 percent of the dietary sodium, or nearly 2000 mg per person per day in just these foods. Figure D6.2 shows the sodium contribution of these 12 food groups as well as the smaller contributions of other foods. It clearly shows numerous foods contribute to the high intake of sodium of Americans.

Figure D6.2. Food sources of sodium



Source: Sources of Sodium Among the US Population, 2005-2006. Risk Factor Monitoring and Methods Branch Website. Applied Research Program. National Cancer Institute. <http://riskfactor.cancer.gov/diet/foodsources/sodium/>. Updated January, 2010. Accessed May 6, 2010a.

## Sodium Modeling

The USDA food patterns are designed to meet the recommendations of the Dietary Guidelines for Americans and the recommendations of the Institute of Medicine's Dietary Reference Intakes. The DGAC conducted a modeling analysis to describe what the sodium levels of the USDA food patterns would be under three scenarios:

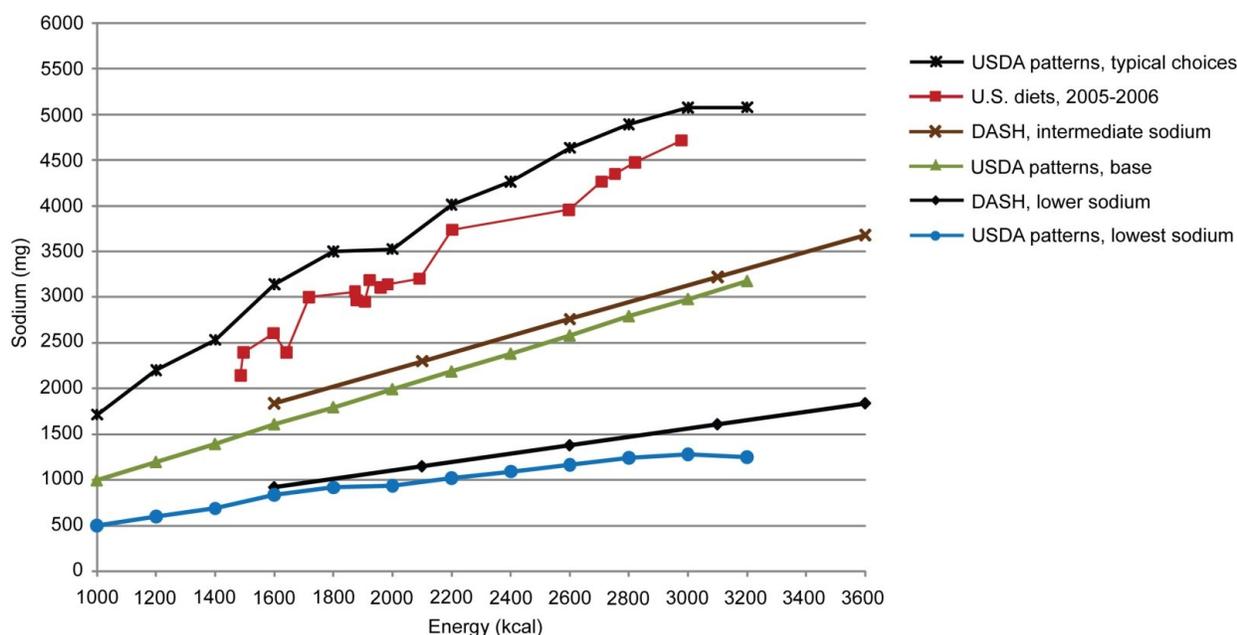
- Scenario 1: The “base” condition, in which nutrient-dense foods, most prepared without salt, are selected as representative foods;
- Scenario 2: A “typical” choices condition (higher than “base”); and
- Scenario 3: A “lower sodium” choices condition in which representative foods inherently high in sodium or with added salt are replaced with lower sodium foods; for example, substituting fresh meats, not those augmented with sodium solutions, for processed meats and using the lowest sodium value currently available on the market for both white breads and quick breads.

The following information summarizes the modeling analysis (see the online Appendix E3.11 at [www.dietaryguidelines.gov](http://www.dietaryguidelines.gov), for details).

In the “base” USDA Food Patterns (Scenario 1), the sodium level, expressed on a per calorie basis, was about 40 percent lower than the estimated sodium intake levels in the US in 2005-2006. Scenario 1 was similar to the intermediate sodium level in the DASH-Sodium trial and close to the recommended Tolerable Upper Intake Level, set by the IOM (2300 mg at about 2000 kcal). If typical, rather than ideal, food choices were to be made (Scenario 2), the sodium level of the patterns would be much higher. In contrast, if only foods with lower sodium content were to be chosen (Scenario 3), the sodium level could be reduced to a level similar to the lower sodium level tested in the DASH-Sodium trial, which is close to the 2005 Dietary Guidelines recommendation for high-risk individuals (1500 mg at about 2000 kcal). This level would be 70 percent below 2005-2006 sodium intake levels.

As shown in Figure D6.3, sodium and energy intakes in all three scenarios are highly correlated; sodium and energy intakes in the diets of Americans are highly correlated; and sodium levels in the DASH-Sodium diets are also highly correlated with energy intake.

**Figure D6.3. Sodium and energy levels in U.S. diets, USDA food patterns at three levels of sodium and DASH diets at two levels of sodium**



Source: USDA, ARS, Food Surveys Research Group, Correlations: Energy & Sodium and Energy & Potassium. Available at <http://www.cnpp.usda.gov/Publications/DietaryGuidelines/2010/Meeting5/Correlations-SodiumAndPotassium-2005-2006.pdf>. Accessed April 15, 2010a.

**Figure D6.3. Data points. USDA patterns, typical choices.**

Energy level (kilocalories)	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200
Sodium level (milligrams)	1715	2201	2533	3143	3499	3527	4012	4267	4635	4893	5075	5078

**Figure D6.3. Data points. U.S. diets, 2005-2006.**

Energy level (kilocalories)	1486	1495	1598	1641	1718	1873	1879	1906	1923	1959	1984	2092	2202	2597	2707	2753	2821	2978
Sodium level (milligrams)	2146	2395	2606	2395	3001	3059	2966	2950	3187	3107	3142	3202	3738	3956	4266	4350	4476	4715

**Figure D6.3. Data points. DASH intermediate sodium.**

Energy level (kilocalories)	1600	2100	2600	3100	3600
Sodium level (milligrams)	1840	2300	2760	3220	3680

**Figure D6.3. Data points. USDA patterns, base.**

Energy level (kilocalories)	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200
Sodium level (milligrams)	996	1195	1392	1608	1795	1993	2186	2381	2580	2791	2979	3176

**Figure D6.3. Data points. DASH, lower sodium.**

Energy level (kilocalories)	1600	2100	2600	3100	3600
Sodium level (milligrams)	920	1150	1380	1610	1840

**Figure D6.3. Data points. USDA patterns, lowest sodium.**

Energy level (kilocalories)	1000	1200	1400	1600	1800	2000	2200	2400	2600	2800	3000	3200
Sodium level (milligrams)	500	600	688	838	918	934	1019	1092	1165	1240	1279	1250

The correlation between sodium and energy intakes in the US among free-living adults is estimated to be 0.80 (USDA/ARS/FSRG/2010a). The menus of controlled feeding studies, such as the DASH-Sodium trial, illustrate how sodium and potassium levels can be designed to be perfectly correlated with energy, that is, the goals for sodium and potassium in DASH-Sodium were set on a per calorie basis. Given the above considerations, it is therefore reasonable, for practical purposes, to adjust sodium targets based on calorie level, given the high correlation between sodium and energy intakes.

### ***Salt Taste Preferences***

Taste preference for sodium is neither fixed nor innate. Rather, it is a malleable trait that is influenced by dietary exposure. At birth, there is no indication that salty substances are distinguishable or preferred (Beauchamp, 1986). Initial appearance of preference for the salty taste occurs at about 4 months postnatal (Beauchamp, 1994; Beauchamp, 1986; Harris and Booth, 1987) but based on the limited evidence available, sodium preferences in infants and children appear to be shaped by dietary exposure (Beauchamp, 1990; Stein et al., 1996). Likewise, sodium preferences in adults and children are influenced by dietary exposure. Studies have demonstrated that reducing dietary sodium intake over a time period of as little as 3 to 4 weeks can decrease preference for salty foods and increase acceptance of foods with reduced sodium content (Bertino, 1982; Cooper and Sanger, 1984).

Several studies document a temporary increased preference or craving for salt over the initial period when sodium intake is reduced (Bertino, 1981; McCance, 2001, Teow, 1985–1986; Yensen, 1959). However, subsequently, a shift in preference occurs such that by 8 to 12 weeks, or sooner in some individuals, preference for less salty foods is established (Bertino, 1982; Mattes and Donnelly, 1991; Mattes, 1997). This phenomenon also has been demonstrated in long-term studies lasting 1 year or more (Blais, 1986). In aggregate, such evidence argues for gradual, step-wise reductions in sodium intake to maximize acceptance of products that are reduced in sodium content.

### ***Strategies to Reduce Sodium Intake***

Recently, the Institute of Medicine issued a report that provides a roadmap to lower the Americans' intake of sodium (IOM Report, 2010). This document noted that activities to reduce sodium intake of the US population have been ongoing for more than 40 years. However, these efforts have been unsuccessful. A major reason is that these efforts were not broad enough in scope to fully address the public health problem of excessive sodium intakes. The current focus on individuals selecting lower-sodium foods and availability of reduced-sodium “niche” products cannot result in intakes consistent with the Dietary Guidelines for Americans by themselves. They must be accompanied by an overall reduction of the level of sodium in the food supply. In other words, the level of sodium to which consumers are exposed on a daily basis from processed and restaurant foods must be reduced. To date, efforts by food processors and the restaurant and foodservice sectors to voluntarily reduce the sodium content of the food supply face obstacles, are not consistently undertaken by all, are not readily sustained, and have proven unsuccessful in lowering overall sodium intake. The IOM made a series of recommendations, many of which involved regulatory actions to gradually lower the sodium content of the food supply. Given safety considerations as well as differences in the amount and function of sodium by type of food product,

reductions in sodium intake will differ by foods (see *Part D. Section 8. Food Safety and Technology* for further information).

## **Question 2: What is the Effect of Potassium Intake on Blood Pressure in Adults?**

### **Conclusion**

A moderate body of evidence has demonstrated that a higher intake of potassium is associated with lower blood pressure in adults.

### **Implications**

Increasing dietary potassium intake can lower blood pressure. A higher intake of potassium also attenuates the adverse effects of sodium on blood pressure. Other possible benefits include a reduced risk of developing kidney stones and decreased bone loss. In view of the health benefits of adequate potassium intake and its relatively low current intake by the general population, increased intake of dietary potassium is warranted. The IOM set the AI for potassium for adults at 4,700 mg per day. Available evidence suggests that Blacks and hypertensive individuals especially benefit from an increased intake of potassium.

### **Review of the Evidence**

As documented in Question 1, elevated blood pressure is a highly prevalent, etiologically relevant, and modifiable risk factor for cardiovascular and renal diseases. A low intake of dietary potassium, especially in the presence of high sodium intake, has been implicated in the pathogenesis of elevated blood pressure. The 2005 DGAC reviewed available evidence from the relationship between potassium intake and blood pressure and concluded that an increased intake of potassium lowers blood pressure. The Committee included evidence from 36 clinical trials and 17 cohort studies (IOM, 2005) in their review. Most of these trials tested potassium supplements, not food sources, typically in the form of potassium chloride pills (Tables 5-4 and 5-5, IOM, 2005). On the basis of these data and in conjunction with other data showing that an increased potassium intake should attenuate the adverse effects of salt on blood pressure, reduce the risk of developing kidney stones, and possibly decrease bone loss, the IOM set the AI for potassium at 4,700 mg per day for adults.

The 2010 DGAC performed an updated search of literature published since 2005 to identify new research on the relationship between potassium intake and blood pressure. A total of 10 new articles met the inclusion criteria and were reviewed. Of the 10 articles, 5 were systematic

reviews/meta-analyses, 4 were randomized trials, and 1 was a three-period, non-randomized cross-over trial. The review by Burgess (1999) was not a formal meta-analysis. Two trials compared potassium chloride to potassium citrate; one of these trials did not have a placebo group. Potassium citrate is the form most similar to that provided naturally in food. Six studies were methodologically strong and four were methodologically neutral.

Each study reported the effects of potassium intake, either from supplements or diet, on blood pressure in adults. Four of the 5 systematic reviews/meta-analyses found a significant reduction in either systolic or diastolic blood pressure, and three found a significant reduction in both. Three meta-analyses of these trials document that, on average, increased potassium intake lowers blood pressure (Cappuccio and MacGregor, 1991; Geleijnse, 2003; Whelton, 1997). In the meta-analysis by Whelton et al. (1997), average net systolic/diastolic blood pressure reductions from a net increase in urinary potassium excretion of 2 g per day (50 mmol per day) were 4.4/2.5 mmHg among hypertensive individuals and 1.8/1.0 mmHg among nonhypertensive individuals. A meta-analysis (Dickinson et al., 2006) did not detect a significant effect of potassium on blood pressure but this meta-analysis applied especially restrictive exclusion criteria and included only five trials. These blood pressure reductions tended to be greatest in hypertensive individuals and Blacks.

Relatively few trials tested the effects of potassium as provided in foods (IOM, 2004, Table 5-3). The potassium in vegetables and fruits is accompanied by bicarbonate precursors rather than chloride. In the initial DASH trial, a diet rich in fruit and vegetables (and therefore rich in potassium) lowered blood pressure (Appel, 1997). Another trial documented that increased vegetable and fruit consumption can significantly lower blood pressure (John, 2002), but that trial did not report the potassium intake of participants on the vegetable and fruit intervention.

Because virtually all trials used potassium chloride supplements, while observational studies assessed dietary potassium intake from foods (paired with nonchloride anions), the effect of potassium on blood pressure appears to result from potassium rather than its conjugate anion. No single trial tested the effects of three or more levels of potassium intake on blood pressure; hence, the dose-response relationship is unclear. Still, blood pressure reductions from supplemental potassium occurred when baseline intake was low (e.g., 1.3 to 1.4 g of potassium per day in Brancati et al. [1996]) and when baseline intake was much higher (> 3.1 g of potassium per day in Naismith and Braschi [2003]).

Evidence from the observational studies and clinical trials has demonstrated heterogeneity in the blood pressure responses to potassium intake. Blacks and hypertensive individuals are more sensitive to the effects of potassium than their non-Black and normotensive counterparts, respectively. Dietary sodium intake also modifies the effects of potassium on blood pressure.

Specifically, the beneficial effects of potassium on blood pressure are greater when sodium intake is high than when sodium intake is low (for details, see DGAC, 2005, Table D7-1).

Some trials have assessed the effects of increased potassium intake on sodium sensitivity, that is, the pressor (blood-pressure raising) response to increased sodium intake. Study populations included nonhypertensive individuals, most of whom were Black (Morris, 1999; Schmidlin, 1999), and hypertensive individuals (Morgan, 1984). These trials are consistent in documenting that potassium attenuates the pressor effects of sodium. One dose-response trial documented that increasing potassium intake to 4,700 mg per day reduced sodium sensitivity in nonhypertensive Blacks (Morris, 1999). In aggregate, these trials highlight the potential benefits of increasing potassium intake in Blacks, a group of individuals with a high prevalence of hypertension and of blood pressure-related cardiovascular and renal diseases.

## **Relevant Contextual Issues**

### ***Effect of Potassium Intake on Cardiovascular Disease Outcomes***

It has been hypothesized that an increased intake of potassium should prevent stroke and coronary heart disease. These beneficial effects could be mediated indirectly through blood pressure (i.e. an increased intake of potassium should lower blood pressure, which in turn should prevent stroke and coronary heart disease) and directly (i.e., independent of blood pressure). To date, several observational studies suggest that increased potassium intake may prevent stroke and perhaps coronary artery disease (IOM, 2004, Table 5-6). However, the evidence is inconsistent and not sufficient to guide dietary recommendations. Recently, a trial documented that a reduced sodium/high potassium salt reduced CVD mortality and medical expenditures in Taiwanese veterans (Chang, 2006). However, it is uncertain whether the effect, if real, resulted from increased potassium, reduced sodium, or both.

### ***Effect of Potassium in Preventing Bone Loss and Kidney Stones***

A diet rich in potassium from vegetables and fruits favorably affects acid-base metabolism because these foods also are rich in precursors of bicarbonate (Sebastian, 1994; Sebastian, 2002). Acting as a buffer, the bicarbonate-yielding organic anions found in vegetables and fruits neutralize acids generated from meats and other high-protein foods. In the setting of an inadequate intake of bicarbonate precursors, bone titrates the excess acid in the blood. This results in demineralization of the bone. Increased bone breakdown and calcium-containing kidney stones are adverse

consequences of excess acid derived from the diet. Therefore, diets rich in potassium with its bicarbonate precursors may help prevent kidney stones and bone loss.

To date, two observational studies have documented that high intakes of potassium (median of 4,000 mg per day in men and 4,700 mg per day in women) are associated with a reduced risk of incident kidney stones (Curhan, 1993; Curhan, 1997). In a third observational study conducted in Finland, the relationship was statistically nonsignificant, perhaps because of the much higher usual levels of potassium consumed in this population (Hirvonen, 1999). In addition, one trial (Barcelo, 1993) documented that approximately 3.6 to 4.7 g of supplemental potassium citrate reduced the risk of recurrent kidney stones. The potassium added to processed foods and the potassium in supplements typically has chloride as the conjugate anion. Because chloride cannot neutralize excess acid in the body, this form of potassium is not expected to help prevent kidney stones or bone loss.

Observational studies, including both cross-sectional studies and longitudinal studies, suggest that increased potassium intake is associated with increased bone mineral density (IOM, 2005, Table 5-7). Trials also have documented that supplemental potassium bicarbonate can reduce bone breakdown and increase bone formation (Sebastian, 1994). However, no trial has tested the effect of increased potassium or diets rich in potassium on bone mineral density or on clinical outcomes related to osteoporosis.

### ***Safety Considerations***

In the generally healthy population with normal kidney function, a potassium intake from foods that exceeds 4,700 mg per day poses no threat of increased risk because excess potassium is readily excreted in the urine. Hence, the IOM did not set a UL for potassium (IOM, 2005). However, a potassium intake below 4,700 mg per day is indicated for individuals whose urinary potassium excretion is impaired. Adverse cardiac effects (arrhythmias) can result from hyperkalemia, which is a markedly elevated serum level of potassium. Common drugs that can substantially impair potassium excretion are angiotensin-converting enzyme (ACE) inhibitors, angiotensin receptor blockers (ARB), and potassium-sparing diuretics. Medical conditions associated with impaired potassium excretion include diabetes, chronic kidney disease, end stage renal disease, severe heart failure, and adrenal insufficiency. As a group, elderly individuals are at increased risk of hyperkalemia because they often have one or more of these conditions or take one or more of the above medications.

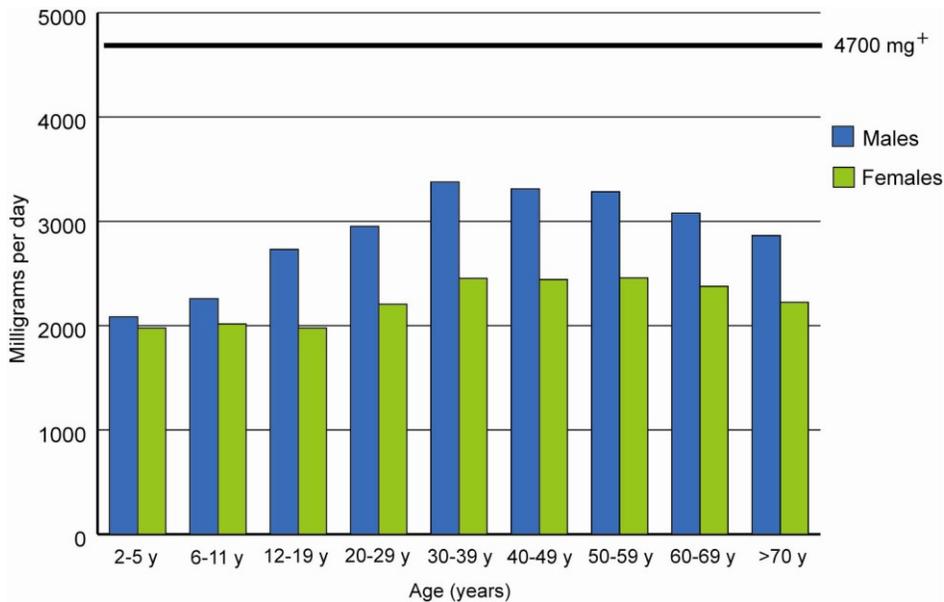
### ***Potassium Intake***

At present, dietary intake of potassium by all groups in the United States is considerably lower than 4,700 mg per day (Figure D6.4). In recent surveys, the mean intake of potassium by adults in

the United States was approximately 3,200 mg per day in men and 2,400 mg per day in women. On average, Non-Hispanic Blacks consume less potassium than Non-Hispanic Whites. Among adults age 20 and older, mean potassium intake was approximately 2,400 mg in Non-Hispanic Blacks and 2,800 mg in Non-Hispanic Whites. Because Blacks have a relatively low intake of potassium and a high prevalence of elevated blood pressure and sodium sensitivity, this subgroup of the population would especially benefit from an increased intake of potassium.

**Figure D6.4. Estimated mean daily potassium intakes, by age/sex group, 2005-2006**

Figure D6.4 vertical bar chart displays mean potassium intake by age and sex. Men average a higher potassium intake compared to women in all age groups. The higher potassium intake in men compared to women and the variation by age likely reflects the high correlation between intakes of potassium and calories. At all ages, mean intake is considerably lower than the 4700 mg per Adequate Intake. The 4700 mg is the Adequate Intake (AI) for potassium intake set by the IOM. For children younger than 14 years old, the AI is less than 4700 mg per day.



+ 4700 mg is the Adequate Intake (AI) for potassium intakes set by the IOM. For children younger than 14 years old, the AI is less than 4700 mg per day.

Source: USDA, ARS, 2005-2006. WWEIA, NHANES. <http://www.ars.usda.gov/Services/docs.htm?docid=13793>.

**Figure D6.4. Data points. All values in milligrams.**

Age (years)	2-5	6-11	12-19	20-29	30-39	40-49	50-59	60-69	>70
Males	2083	2258	2730	2951	3377	3311	3283	3077	2863
Females	1977	2016	1976	2205	2453	2443	2458	2376	2223

### ***Food Sources of Potassium***

Table D2.14 in *Part D. Section 2: Nutrient Adequacy* lists foods that are among the best sources in potassium, when considered in typically eaten portion sizes. However, consumption of many of these potassium sources is relatively low in the US, and therefore due to their frequency of consumption, other foods provide most of the potassium currently consumed. At present, the top five contributors of potassium for all persons, and their mean contribution to overall potassium intake, are reduced fat (2% and 1%) milk (154 mg/day), coffee (135 mg/day), chicken and chicken mixed dishes (119 mg/day), beef and beef mixed dishes (94 mg/day), and 100% orange/grapefruit juice (90 mg/day). Table D2.15 in *Part D. Section 2: Nutrient Adequacy* provides additional information about the major food sources of potassium in US diets (NCI, 2010b).

### **Potassium Modeling**

The DGAC examined potassium intakes by the US population, the levels of potassium in the base USDA food patterns, and the levels of potassium in the DASH-Sodium trial diets. These intakes and levels were described in terms of absolute potassium intake (mg/day) and as mg per kcal. Just as for sodium, there is a high correlation between energy intake and potassium intake ( $r=0.72$ ) (USDA/ARS/FSRG, 2010a). This high correlation makes interpretation of cohort studies difficult. The following information summarizes the modeling analysis (see the online Appendix E3.12 at [www.dietaryguidelines.gov](http://www.dietaryguidelines.gov), for details).

While the target level of potassium for all USDA base food patterns was 4700 mg per day; this level was not met at most calorie levels. Only at the 3000 and 3200 calorie levels was the target met. The potassium/energy ratios range from 1.5 to 1.9 mg/kcal. An important feature of the patterns is the high correlation of potassium and energy ( $r=0.98$ ). Therefore, like sodium, the potassium in the USDA food patterns is effectively, but not intentionally, calorie adjusted. Unlike the targets for the USDA patterns, the potassium targets for the DASH diets were designed to be proportional to energy intake and provided 4258 mg potassium/2000 kcal (Pao-Hwa, 2003). Therefore, for practical purposes, it is reasonable to adjust potassium targets based on calorie level, given the high correlation of potassium and calorie intakes in the population.

The menus developed for the DASH trials intentionally included vegetables and fruits that were especially high in potassium to meet the potassium targets. The USDA food patterns, on the other hand, use composite potassium values of all the fruits and each vegetable subgroup. These values reflect a weighted population mean intake of all vegetables and fruits in each subgroup. (They also reflect the weighted population mean intake of all other food groups and subgroups.) The potassium/calorie ratios in the DASH diets ranged from 1.9 to 2.5 mg/kcal, somewhat higher than

the USDA pattern ratios, which range from 1.5 to 1.9 mg/kcal, and much higher than the current potassium average potassium/energy intake ratio (1.2).

The DGAC also determined the contribution of coffee and tea consumption on potassium intake. In 2005-2006, adults aged 19 years and older drank an average of about 18 fl. oz. of coffee or tea per day. These beverages provided an average of 247 mg of potassium per day. On a given day, 66 percent of adults drink coffee and/or tea, and 90 percent drink these beverages at least once in a year (USDA/ARS/FSRG, 2010b). The food pattern modeling analysis revealed that the potassium levels in the current USDA food patterns would be increased by 5 to 8 percent if the mean amounts of coffee and tea consumed by adults were assumed to be included in the patterns designed for adults (i.e., 1600 calories and higher).

### **Question 3. What Amount of Water is Recommended for Health?**

#### **Conclusion**

Based on an extensive review of evidence, an IOM panel in 2004 concluded that the combination of thirst and usual drinking behavior, especially the consumption of fluids with meals, is sufficient to maintain normal hydration. However, because water needs vary considerably and because there is no evidence of chronic dehydration in the general population, a minimum intake of water cannot be set.

#### **Implications**

In order to prevent dehydration, water must be consumed daily. Healthy individuals who have routine access to fluids and who are not exposed to heat stress consume adequate water to meet their needs. Purposeful drinking is warranted for individuals who are exposed to heat stress or who perform sustained vigorous physical activity. Although uncommon, heat waves are one setting of extreme heat stress that increases the risk of morbidity and mortality from dehydration, especially in older-aged persons. In view of the ongoing obesity epidemic, individuals are encouraged to drink water and other fluids with few or no calories.

#### **Review of the Evidence**

Recommendations for water are made to prevent the deleterious, primarily acute, effects of dehydration. These effects include impaired cognitive function and motor control. Although a low intake of water has been associated with an increased risk of kidney stones and other chronic diseases, this evidence was insufficient for the 2005 DGAC to establish quantitative recommendations for water consumption. The 2010 DGAC conducted exploratory literature searches on the relationship of water intake with hydration, kidney stones, body weight, and cancer. These searches revealed that for the purposes of identifying health problems related to water intake

in the general population, little additional evidence on these topics has been published after the 2005 DGAC report.

The primary indicator of hydration status is plasma or serum osmolality. Appendix G-1 from the 2004 IOM report (IOM, 2005) provides the serum osmolality by decile of total water intake in the third National Health and Nutrition Examination Survey (NHANES III). Serum osmolality concentrations in each decile were essentially identical (the maximum range between the lowest and highest decile was only 3 mmol/kg in each age group). These data indicate that people in the lowest and highest deciles of total water intake were neither systematically dehydrated nor overhydrated. Importantly, this pattern of findings was evident throughout the lifespan. In infants and children as well as community-dwelling older-aged persons, no evidence of dehydration existed except when deprived of water due to illness or lack of mobility. Although it is well-documented that older individuals have reduced ability to concentrate and dilute their urine (Brenner and Rector, 2007) and have reduced thirst in the setting of water deprivation (IOM, 2005; Farrell, 2008), there is no evidence that even older individuals experience dehydration, except under conditions of extreme heat stress. Over-hydration is an uncommon medical problem that occurs in a few unusual settings, such as psychogenic polydipsia in patients with severe mental illness or forced water consumption as part of hazing rituals.

Although uncommon, heat waves are one setting of extreme heat stress that increases the risk of morbidity and mortality from dehydration, especially in older-aged persons. One of the worst heat waves occurred in France in 2003. Nearly 15,000 excess deaths occurred (Fouillet, 2006). While virtually all age groups were affected, older-aged persons ( $\geq 75$  years old) were disproportionately affected. Risk factors for adverse outcomes included concurrent medical conditions, as well as social factors, such as living alone. Still, excess deaths occurred in older-aged persons living in institutional settings. Overall, these data indicate the need for purposeful drinking by broad segments of the population, not just older-aged persons, in the setting of extreme heat stress, such as heat waves.

Total water intake includes drinking water, water in beverages, and water contained in food. Because normal hydration can be maintained over a wide range of water intakes, the IOM set the AI for total water based on the median total water intake from US survey data (IOM, 2005). The AI for total water intake for men and women age 19 to 30 years is 3.7 liters and 2.7 liters per day, respectively. In NHANES III, fluids (drinking water and beverages) provided 3.0 liters (101 fluid ounces; approximately 13 cups) and 2.2 liters (74 fluid ounces; approximately 9 cups) per day for men and women age 19 to 30 years, respectively. Fluids represented approximately 81 percent of total water intake. Water contained in food provided the remaining 19 percent of total water intake.

The AI should not be interpreted as a specific requirement or recommended intake. Individual water requirements can vary greatly, even on a day-to-day basis, primarily because of differences in physical activity and environmental conditions and differences in diet. Dietary factors influence water requirements because total water consumption must be sufficient to excrete metabolites of protein and organic compounds, as well as excess electrolytes. Increased water intake is typically required by those individuals who are very physically active or who are exposed to high temperatures. In individuals who are neither physically active nor exposed to heat stress, daily consumption below the AI can be sufficient to maintain normal hydration.

## Chapter Summary

At present, Americans consume excessive sodium and insufficient potassium. The health consequences of excessive sodium and insufficient potassium are substantial and include increased levels of blood pressure and its sequelae (heart disease and stroke). Water is needed to sustain life; except under unusual circumstances, there is no evidence that water intake is either excessive or insufficient.

## Needs for Future Research

1. Conduct studies, including clinical trials, in children to determine the effects of sodium on blood pressure and the age-related rise in blood pressure

**Rationale.** The problem of elevated blood pressure begins in childhood, well before blood pressure levels cross the threshold that defines hypertension in adults (140/90).

2. Conduct trials that determine the effects of sodium reduction on clinically relevant non-blood pressure variables, such as left ventricular mass, proteinuria, and bone mineral density.

**Rationale.** An inclusive body of evidence suggests that the benefits of a lower sodium intake extend beyond reduced blood pressure. Evidence from cross-sectional studies has documented that sodium is directly associated with left ventricular mass and proteinuria. Clinical trials have also documented that a higher intake of sodium increases urinary calcium excretion.

3. Conduct controlled trials that test whether increased potassium intake through supplements or potassium-rich foods increase bone mineral density.

**Rationale.** A consistent body of evidence from observational studies indicates that increased intake of potassium from foods is associated with greater bone mineral density and with

evidence of reduced bone turnover. Data from small trials also have documented that increased intake of potassium reduces bone turnover.

4. Conduct dose-response trials that test the main and interactive effects of sodium and potassium intake, as well as possible impact of other minerals (e.g., calcium, magnesium) on blood pressure and other clinically relevant outcomes.

**Rationale.** There remains a need for dose-response trials, particularly for potassium, that span a clinically relevant range of dietary intake. Also, the interactive effects of sodium and potassium are of considerable interest.

5. Investigate the role of increased total fluid intake as a means to prevent chronic diseases.

**Rationale.** A few studies suggest that increased fluid consumption might reduce the risk of bladder cancer, urinary tract infections, kidney stones, and colon cancer. However, this evidence was insufficient to make recommendations on fluid intake.

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